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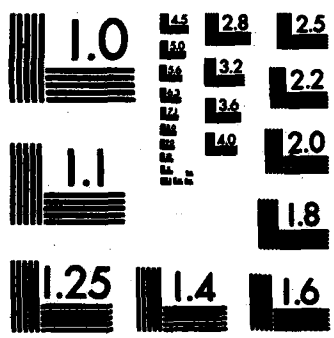

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DEPARTMENT OF EDUCATION.

College of Agriculture and Life Sciences

CORNELL UNIVERSITY

THE INFORMATION CONTENT OF PICTURE-TEXT ASSEMBLY INSTRUCTIONS

George R. Bieger
Marvin D. Glock

Technical Report No. 5

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A taxonomy of the categories of information depicted in picture-text instructions for two procedural assembly tasks was developed and used experimentally. Three categories of information were hypothesized to be the "necessary and sufficient" information for successful execution of the procedures. Various combinations of information were presented to 108 subjects, each in one of 36 instructional conditions. Comparison of performance data for two tasks indicated that subjects using "complete" instructions finished the assemblies

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ABSTRACT

A taxonomy of the categories of information depicted in picture-text instructions for two procedural assembly tasks was developed and used experimentally. Three categories of information were hypothesized to be the "necessary and sufficient" information for successful execution of the procedures. Various combinations of information were presented to 108 subjects, each in one of 36 instructional conditions. Comparison of performance data for two tasks indicated that subjects using "complete" instructions finished the assemblies in significantly less time and with significantly fewer errors than did those using "incomplete" instructions, thus confirming the experimental hypothesis.

THE INFORMATION CONTENT OF PICTURE-TEXT ASSEMBLY INSTRUCTIONS

A major criticism of past research on pictures and texts has been that the materials used in that research were rarely described in terms of their relevant characteristics (Stone, 1980). One possible remedy is the development and use of a "taxonomy" of categories of information to classify the content of such picture-text materials in a way that would permit generalizability to other materials. This paper describes the procedures employed in developing such a taxonomy for procedural assembly instructions and the initial attempts to validate that taxonomy empirically.

There has been little research done in the area of identifying the information content of either text or pictures. Some work in semantic analysis has investigated the semantic roles filled by concepts as well as the semantic relationships among concepts in prose passages. Fillmore (1968) identified several "cases" that linguistic entities can occupy. Examples of these cases include:

> Agentive - The case of the typically animate perceived instigator of the action identified by the verb.
>
> Instrumental - The inanimate force or object casually involved in the action or state identified by the verb.

These cases, which were incorporated into several other prose grammars (e.g., Kintsch, 1974; Meyer, 1975), identify the kind of semantic role that a particular concept fills in a given sentence, proposition, or idea unit. The semantic relationships among concepts were classified by Grimes (1975), whose predicate relationships were also adopted by other analysis models (e.g., Meyer, 1975). Some examples of these

predicates include:

<u>Covariance</u> - Relations often referred to as results or purposes with one argument serving as the antecedent and the other serving as the consequent.

<u>Response</u> - Equally weighted question(s) and answer(s), remark and reply, or problem(s) and solution(s).

Both of the classification systems illustrated above pertain most appropriately to linguistic analyses of specific concepts conveyed through discourse. They try to show how the same words can convey different meanings when organized in different ways. They do not attempt to characterize the broad categories of information that a passage contains. The one notable attempt to identify the categories of information avaliable in a stimulus was a taxonomy of information contained in pictures developed by Mandler and Parker (1976) and expanded by Mandler and Johnson (1976). This taxonomy identified four categories of information:

1. <u>Inventory information</u> - specifies what objects a picture contains.
2. <u>Spatial location information</u> - specifies where objects are located.
3. <u>Descriptive information</u> - specifies the figurative detail of the objects contained in the inventory.
4. <u>Spatial composition information</u> - specifies the areas of filled or empty space and the density of filled space.

This taxonomy referred only to the information available in pictures and did not include actions or reference to what could be inferred to be happening in the picture.

Using the Mandler and Johnson (1976) taxonomy as a base, and adding relevant categories from semantic case roles (Fillmore, 1968) and predicate relationships (Grimes, 1975), the development of a taxonomy of the

information available in procedural picture-text instructions was begun. The first step involved the identification of the kinds of information that people used when performing assemblies. This was accomplished by having twenty undergraduate student volunteers perform two assemblies, using a completed product as a guide, while being videotaped and while "thinking out loud" as they worked. One task was the assembly of a model hand truck from a set of blocklike parts and the other task involved the construction of a multi-colored geometric pattern from pre-cut felt pieces. Some of these subjects were asked to return to view their videotapes and add information about what they were doing, thinking, etc. throughout the assemblies. From all of these sources a description of the information used in the assemblies was collected, condensed, and compared with a "core" of instructions that had been developed earlier. This comparison resulted in the addition, modification, or deletion of several pieces of information for each set of instructions.

The second step of the taxonomy development involved the re-analysis of the modified instructions using a discourse analysis system (Frederiksen, 1975; Pine & Bieger, 1980). Having produced a list of propositions which contained all of the information necessary for the assembly, an attempt was made to classify each proposition according to one of the categories described by Mandler and Johnson (1976). In cases where no category seemed appropriate, a new category was defined, using the case roles of Fillmore (1968) and the predicate relationships of Grimes (1975) as guides. A list of the categories of information which accounted for all of the propositions, and the definitions of those categories, can be found in Table 1.

Insert Table 1 about here

Two new raters were trained in the use of the categories and were then asked independently to assign each proposition to one of the categories. The assignments for each proposition were then compared among the three raters. The results of this inter-rater comparison are shown in Table 2.

Insert Table 2 about here

As can be seen in Table 2, there was a high degree of agreement among raters, suggesting an accurate assignment of propositions as well as a reliable assignment. Even in the cases where there was not unanimous agreement, consensus was quickly achieved after a brief discussion.

To proceed to the next step of preparing stimulus materials the categories of information had to be examined to determine the various ways in which they could be depicted in text and pictures. Before describing how the manipulations to the information were determined, a thorough explanation of the taxonomy might be helpful. A more complete description of the categories of information, including relevant examples, follows.

Categories of Information

Inventory information

This information specifies the objects and concepts that are depicted in the stimulus. Inventory information in the text is usually the names of the objects (or concepts), and in illustrations is the pictorial

depiction of the actual object. In the following example the underlined portions constitute the inventory information:

Connect <u>three</u> <u>large</u> <u>blocks</u> and <u>a</u> <u>small</u> <u>block</u> end to end.

In many situations the pictorial depiction of an object provides the referent for something mentioned in the textual portion of the instructions. This was not the case in the present study in which the names and pictorial representations of objects were learned by subjects at the start of each session.

<u>Descriptive information</u>

This information specifies the figurative detail of the objects or concepts depicted, that is, what the object looks like. In the present research, the descriptive information relevant to the tasks, such as details about the tab and grooves on the blocks, was learned by the subjects with the inventory information at the beginning of each session.

<u>Operational information</u>

This information directs an agent to engage in a specified action. Often the agent is implied, as in imperative constructions such as:

<u>Connect</u> three large blocks and a small block.

In this case, the implied agent is the reader and the specific operation is one of "connection." Similarly, the operation itself is often not explicit in the stimulus but must be inferred by the reader. This is especially true of pictorial depictions in which the arrangement of objects implies an operation. In a pilot study, during which subjects were asked to describe pictures, many responses included descriptions which reflected inferences about operations to be performed on objects.

Spatial information

This information specifies the location, orientation, or composition of an object.

Location - describes the position of an object in space in relation to another object or fixed point of reference. For example: The large block beneath the small block.

Orientation - describes the orientation in space of an object. For example: The end of the block pointing up.

Composition - specifies areas of filled or empty space and the density of filled space. Pictorially, this information is equivalent to figure-ground relationships which enable a viewer to discriminate objects from their backgrounds.

Contextual information

This information provides the theme, or organization, for other information which may precede or follow it. Context, in procedural instructions, is typically information about the general outcome of following certain procedures. In assembly tasks this takes the form of either a verbal or pictorial depiction of the finished product of a sequence of instructions.

Contextual information can occur at different levels of a procedural sequence, with its utility depending on where it occurs. One can conceptualize the construction of the loading cart as the hierarchy of subassemblies shown in Figure 1. In this hierarchy, the product of a given subassembly

---

Insert Figure 1 about here

---

can act as the context for the steps of that procedural sequence. For example, the notion of "a column" can provide a context for operations involving the three large blocks and the small block. Similarly, the notion of the "back" provides the context for joining the columns with the flat pieces, and the notion of the "loading cart" provides a global context for joining all of the individual subassemblies.

The nature of contextual information in procedural assembly instructions is gross, undetailed, spatial or temporal information. It may provide, for example, the overall shape of the finished loading cart if it is provided pictorially; or, if presented in text, it might convey the general location of a subassembly by referring to "the back." Since it does not provide very detailed spatial or temporal information, the effect of a given piece of contextual information, on the performance of a specific operation, is likely to be a function of its proximity to that operation. That is, the knowledge that the final product of the entire assembly will be a model loading cart is not likely to enhance performance in constructing a column. That knowledge is, however, likely to be beneficial when connecting the base and back, or when installing the handles.

Covariant information

This information specifies a relationship between two or more other pieces of information which vary together, such as a cause and effect, a problem and solution, or an action and a goal or result. In the example below, the underlined words signal the covariant relationship:

> Connect the rod and the clip so that the clip is in the middle of the rod.

Results, effects, and goals differ from contextual information in that they describe a particular state of affairs in a rather detailed

fashion, whereas contextual information conveys a more general sense of the outcome of a sequence of procedures.

Temporal information

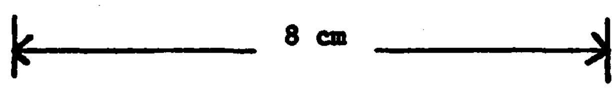
This information specifies the time course of a series of states or events. In the textual portion of instructions, time can be indicated either by use of tense markers or by the use of individual words that connote sequence, such as "first," "next," "then," and "finally." In pictures, temporal information can be conveyed either by numbers indicating sequence or by the decomposition of a complex picture into a sequence of simpler pictures.

Qualifying information

This information modifies other information by specifying the manner, attributes, or limits of that information. Qualifying information is typically provided textually and usually takes the form of an adjectival or adverbial phrase. For example, in the following sentence the exactness of the distance between columns is qualified by "about."

> Arrange the columns so that they are *about* two block widths apart.

In pictures, such inexactness is generally assumed unless more precise measurements are indicated by the use of drafting notation, such as:



Emphatic information

This information directs attention to other information. In pictures, bold lines, arrows, or differential use of colors can all be used to emphasize some aspect of a depiction. In text, underlining, italics, capitalization, and the use of phrases such as "be sure that" or "notice"

all can be used for emphasis.

Once this taxonomy of categories of information was completed, methods for depicting the certain categories, separately and in all possible combinations, in both text and picture, were explored. The identification of the categories selected for manipulation and the rationale for that choice is discussed below.

Modes of Presentation

It quickly became apparent that the full taxonomy contained an unmanageable number of classifications. Further examination of the instructions revealed that four categories of information were present at almost every step of both assembly sequences. These ubiquitous categories included Inventory, Operational, Spatial, and Contextual information. The remaining categories of information were all present in both sets of instructions but with much less frequency. The regularity with which the four most frequent categories appeared in two different assembly tasks suggested that they might constitute the more essential information. Reexamination of the protocols of subjects used in the information description sessions revealed that the pieces of information most frequently mentioned by subjects were precisely those items falling into the four more ubiquitous categories. This observation supported the hypothesis that these four categories of information may contain the necessary, and perhaps sufficient, information for successful completion of the assembly tasks. If it were possible to depict each of these categories of information, separately and in all possible combinations with each other, in text alone and in pictures alone, a matrix of possible text-picture combinations could be constructed.

It was decided, in the interest of making the possible combinations

still more manageable, that since the experimental paradigm of teaching the object names (including their relevant features and pictorial and verbal identities) to 100% mastery had proven successful in previous studies, the category of inventory information would not be included for manipulation. Object depictions and names would be used as adjuncts to operational information, but would not be varied as a separate category.

Preparation of "text alone" versions of the instructions containing each of the three categories (Operational, Spatial, and Contextual) soon exposed several problems. It became apparent that certain kinds of information could not be meaningfully depicted in isolation. For example, spatial information is essentially meaningless unless inventory information is present. It would not be realistic to have instructions that convey notions like "end to end." If, however, inventory information is added, many readers often find that certain operations are implied. Similar problems arose with contextual information. Since much of what we call context is a kind of spatial information, especially in assembly tasks, it became apparent that the depiction of local contextual information was frequently confounded with both spatial and operational information.

The problems of isolating categories of information became even more apparent with the preparation of picture versions of the instructions. How, for example, does one depict context pictorially? The answer, according to several commercial graphic artists, is by drawing the finished product. However, a pictorial depiction of the "column" gives, in addition to local context, explicit spatial information and implicit

operational information. For this reason it was decided to eliminate completely all local contextual information and to manipulate contextual information only at the highest level.

These problems prompted the elimination of several potential combinations of information. Given the three selected categories of Operational (O), Spatial (S), and Contextual (C) information, there existed the potential for eight combinations in both text and pictures. (Nothing, O, S, C, O+S, O+C, S+C, and O+S+C). This would have resulted in a matrix of picture-text modes of presentation containing 64 cells. After eliminating several combinations because of the artificiality or impossibility of presentation, six combinations remained in both text and pictures (Nothing, O, C, O+S, O+C, O+S+C). The six combinations of information generated a presentation matrix consisting of 36 cells. This matrix is shown in Figure 2.

Insert Figure 2 about here

The categories of information, the combinations within modes (text or picture), and the presentation matrix were taken to a graphic artist and technical illustrator who described the ways in which the various pictorial combinations could be depicted. These depictions were made using line drawings that were modified as necessary. Textual materials were also developed to convey the same combinations of information. Finally, the two sets of materials were assembled into 36 sets of instructions (i.e., 36 modes of presentation) for each assembly, corresponding to the information categories indicated in the presentation matrix in Figure 2.

Of the 36 sets of instructions, 15 were identified as "complete," that is, containing all three of the critical categories of information hypothesized to constitute the necessary and sufficient information for execution of the instructions, and 21 were identified as "incomplete," that is, missing one or more of the critical categories of information.

An experiment was designed to determine the validity of the critical categories of information as the "necessary and sufficient" information for successful completion of the assembly tasks; and, to investigate the effect, on speed and accuracy of assembly, of variations in the location (in text, picture, or both) of the different categories of information.

Method

Subjects

One-hundred and eight students enrolled in various undergraduate courses were asked to volunteer to participate as subjects in this research and received credit toward course requirements in exchange for their assistance. Termination of a subject's participation was permitted at any time without penalty, and the privacy of all participants was safeguarded by omitting identification data from all record forms.

Materials

(a) Instructions for two assembly tasks, prepared and arranged according to the procedures described earlier (see Appendix for samples of various instructions).

(b) Experimenter prepared fabric pieces and tools for the construction of the fabric craft task designed by the authors.

(c) Fischer-Technik 100 Model Kit for the construction of the model loading cart.

(d) Digital stop clock for the recording of assembly times.

(e) Sanyo Model VC 500 video camera for the collection of performance data.

(f) Sanyo Model VTC 7100 video tape cassette recorder for the storage of performance data.

(g) Experimenter prepared information and scoring forms. These forms allowed the collection of background data on subjects (e.g., age, major, etc.) and the recording of assembly times and errors for each step of both assemblies.

Procedures

1. Subjects were briefed on the purpose of the study and the nature of their participation was explained.
2. The parts for the first task were introduced, using a parts identification chart. The name of the part itself, its notable features, and its pictorial depiction were pointed out to the subjects.
3. Subjects were given as much time as needed to memorize the part names and identities.
4. An informal quiz was administered to subjects, who were required to know the names and identities of all parts to 100% mastery. If a subject missed any item(s) on the quiz he/she was corrected, given additional time to study the parts, and requizzed until 100% mastery was achieved.
5. Subjects were given one of the 36 sets of instructions for the first task and were instructed to read and follow the instructions.
6. Assemblies were scored for time and accuracy while in progress and the tape was kept until the completeness of all data was insured and interrater reliability was assessed.

7. When the subjects indicated completion or desire to stop the first task, procedure steps 2 through 6 were followed for the second task. The set of instructions for the second task was matched to the first set using row-column complements based on the presentation matrix shown in Figure 2. The order of tasks (i.e., felt task or loading cart first) was staggered (A-B, B-A, B-A, A-B, etc.).
8. Following completion of the second task, subjects were fully debriefed, were allowed to obtain answers to all of their questions, and were informed of their opportunity to receive a full explanation of results and conclusions when available.

Results

Experiment I had as its objective the confirmation of the hypothesis that the three categories of information chosen (i.e., Operational, Spatial, and Contextual) constituted the necessary and sufficient information for completion of the assemblies.

Data from three replications of the presentation matrix shown in Figure 2 were recorded and analyzed according to completeness of instructions. Mean assembly times and mean number of errors, for complete and incomplete groups on both tasks, are shown in Table 3. These data were compared using a one way ANOVA. The results of this comparison are summarized in Table 4. This analysis indicates that on both assemblies subjects receiving complete instructions completed the assemblies in significantly less time, and with significantly fewer errors, than those subjects using incomplete instructions. Further examination of the range of errors for each group indicates that on both tasks the least accurate subject using complete instructions made fewer errors than the most accurate subject

using incomplete instructions (2 as opposed to 5 errors on the loading cart assembly, and 3 as opposed to 4 errors on the felt task). Although there was some overlap in the ranges of assembly times between groups, the means were found to be significantly different even when extreme values (i.e., possible "outliers") were omitted.

Discussion

Cursory examination of the results from this experiment suggest, that the characterization as "necessary and sufficient," of the three categories of information identified as important was indeed accurate. Not only were there statistically significant differences on all dependent measures between complete and incomplete instructional conditions, but these differences were of such magnitude that their educational significance was self-evident. For example, on both tasks, the least accurate of all subjects receiving complete instructions still made fewer errors than the most accurate of all subjects receiving incomplete instructions. Indeed, these three categories of information (operational, spatial, and contextual) appear to be very important to the successful execution of procedural assembly instructions, and at least in regard to the instructions used in this experiment they do in fact seem to warrant their characterization as the necessary and sufficient information for the successful completion of the assembly tasks.

This finding suggests that the categories of information, identified in the taxonomy developed here, may be a functional classification mechanism for describing the information content of procedural instructions. The fact that the three manipulated categories of information had such a dramatic impact on both accuracy and speed of performance suggests that these results may have important implications for the design of procedural assembly

instructions. In such instructions it is very important that these categories of information be conveyed, even if no other information is used. In those situations where only limited amounts of information are possible, it would be most beneficial to limit the information content to these categories. For example, on many kinds of machinery there are often instructions for specific operations on the equipment. Typically, these instructions must be brief, due to space limitations, and try to include only the most important information. The results of this study suggest that the important kinds of information for assembly instructions, when inventory information is already known, are spatial, operational, and contextual.

Much research in the area of pictures and texts has been faulted for not describing the content of the materials in regard to their relevant characteristics. This taxonomy was developed with the hope that it would identify some of those relevant characteristics. The results of this first study indicate that that hope was realized. The taxonomy seems to have identified important categories of information for procedural assembly instructions. It remains to be seen whether or not these categories demonstrate comparable utility in other types of procedural instructions or with nonprocedural picture-text materials. This taxonomy may provide the foundation for the development of a taxonomy of information contained in picture-text materials in general. One may be able to use such a classification device to compare, or at least describe, different types of materials in relation to the distribution of various categories of information. For example, it may be that a functional difference between such procedural tasks as assemblies and troubleshooting is the relative frequency of one or another category of information. If such a relationship

could be found, tasks could be classified accordingly, and instructional materials which emphasize the important information for a particular task could be designed in order to maximize performance (either speed, accuracy, or both).

A limitation of the research reported in this thesis is that examination of tasks other than assembly tasks was not done. This was intentional. However, the generalizability of these results is nevertheless restricted. Future research in this area might examine the relevance of these categories of information to other tasks, such as reading for information and reading for enjoyment, and attempt to identify the important categories of information, without which a set of instructions could not be comprehended and executed.

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FOOTNOTE

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Table 1

Categories of Information

Inventory. - information which specifies what objects or concepts are depicted.

[illegible] - information which specifies the figurative detail of the objects or concepts depicted.

[illegible] - information which directs an implied agent to [illegible] a specified action.

[illegible] - information which specifies the location, [illegible], or composition of an object.

> [illegible] - describes the position of an object in [illegible] in relation to another object or fixed point of reference.
>
> [illegible] - describes the orientation in space of an [illegible].
>
> [illegible] filled or empty space [illegible]

[illegible] - information which [illegible] the theme or [illegible] which may precede or [illegible].

[illegible] - information which specifies a relationship [illegible] pieces of information which vary [illegible].

[illegible] - information about the time course of states or [illegible].

[illegible] - information which modifies other information by [illegible], or limits of that information.

[illegible] - information which directs attention to other information.

Table 2

Inter-rater Agreement on Classification of Propostions

	Unanimous Agreement	Agreement By Two Raters	No Agreement
Number (149)	137	8	4
Percent of Total	91.95	5.37	2.68

Table 3

Mean Scores for Complete and Incomplete Groups

	Loading Cart		Felt Task	
	Complete	Incomplete	Complete	Incomplete
Time of Assembly (seconds)	675.6	1075.6	627.1	763.8
Errors	0.51	15.54	0.82	12.86
Number of Subjects	45	63	45	63

Table 4

ANOVA Table for Completeness Data

Source	df	MS	F	p
Loading Cart				
Assembly Times:				
Treatment	1	4200400.01	21.53	.0001
Error	106	195101.28	--	--
Errors:				
Treatment	1	5928.77	106.46	.0001
Error	106	55.69	--	--
Felt Task				
Assembly Times:				
Treatment	1	490565.04	6.75	.0107
Error	106	72674.38	--	--
Errors:				
Treatment	1	3802.03	90.23	.0001
Error	106	42.13	--	--

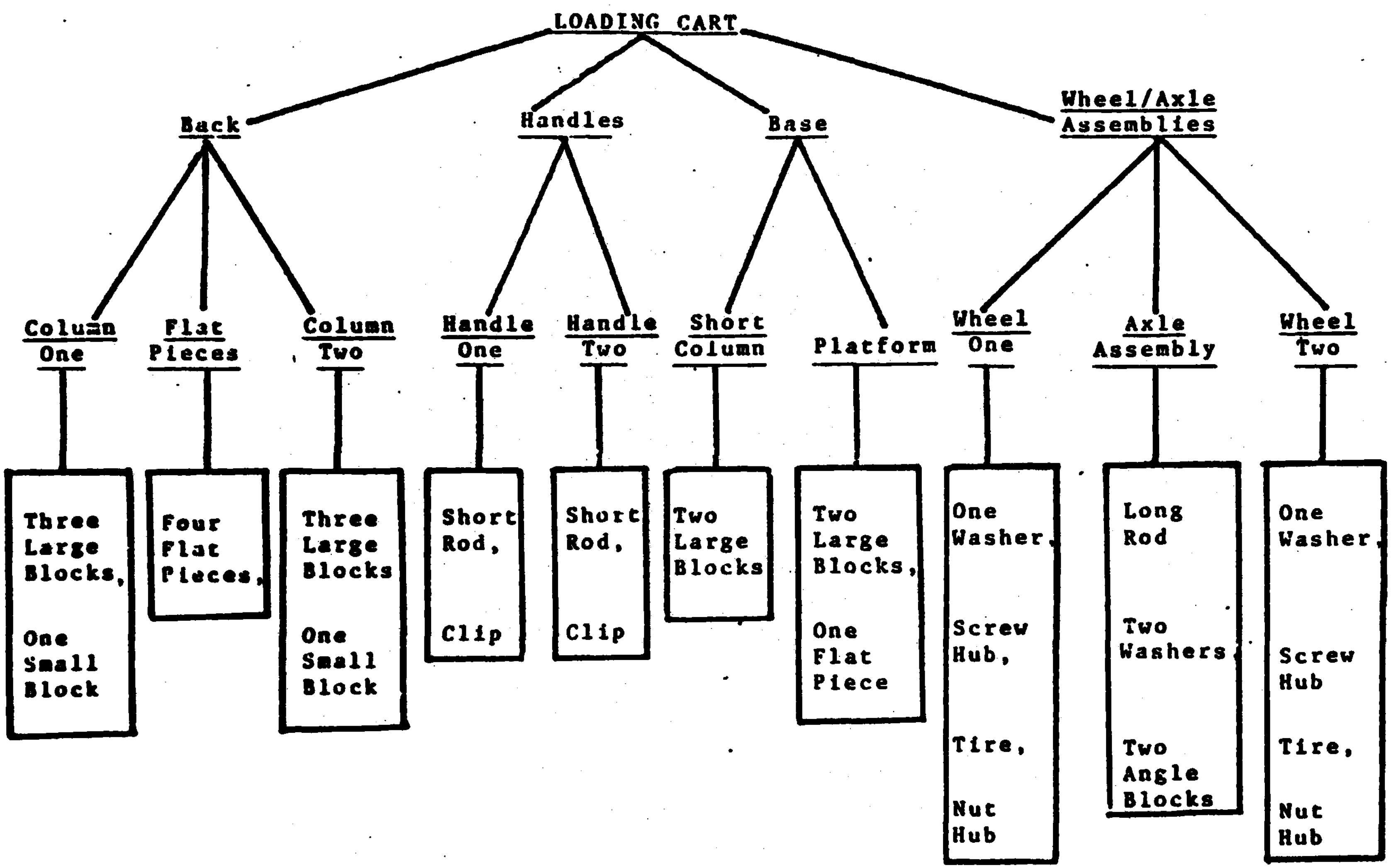


Figure 1. Hierarchy of Subassemblies for the Loading Cart Construction

TEXT

PICTURE	Nothing	O	C	O+S	O+C	O+S+C
Nothing	---	---	---	---	---	X
O	---	---	---	---	---	X
C	---	---	---	X	---	X
O+S	---	---	X	---	X	X
O+C	---	---	---	X	---	X
O+S+C	X	X	X	X	X	X

Key: O = Operational Information
C = Contextual Information
S = Spatial Information
--- = Incomplete mode of presentation
X = Complete mode of presentation

Figure 2. Modes of Presentation Indicating Combinations of Categories of Information that are Practically Capable of Being Depicted in Each Source (Text and Picture).

Appendix

Representative Samples of Different Instructional Combinations

TEXT

Operational Only

Loading Cart:

Connect three large blocks and a small block.

Felt Task:

Arrange the rectangle and mark it.

Operational and Spatial

Loading Cart:

Connect three large blocks end to end and connect a small block to the tab end of this structure.

Felt Task:

Arrange the rectangle so that the short edges are at the top and bottom and the long edges are on the sides. Find and mark the midpoints of each side and the center of the rectangle.

Contextual

Loading Cart:

Construct a model hand truck.

Felt Task:

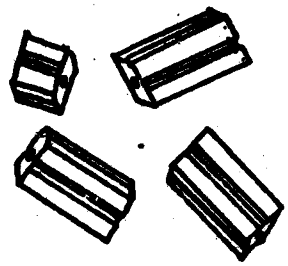
Make a decorative wall hanging.

Appendix . (continued)

PICTURE

Operational Only

Loading Cart:



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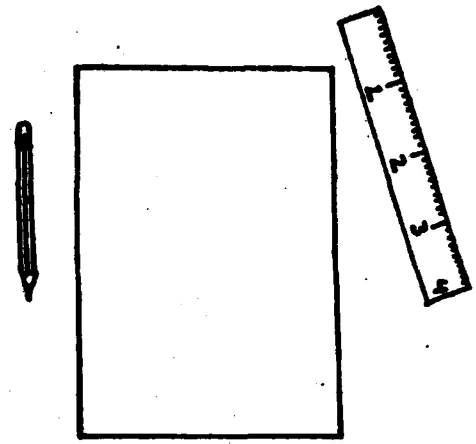

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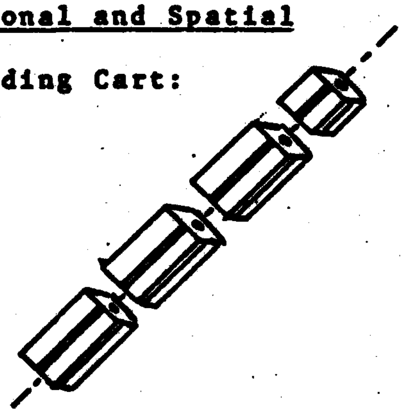

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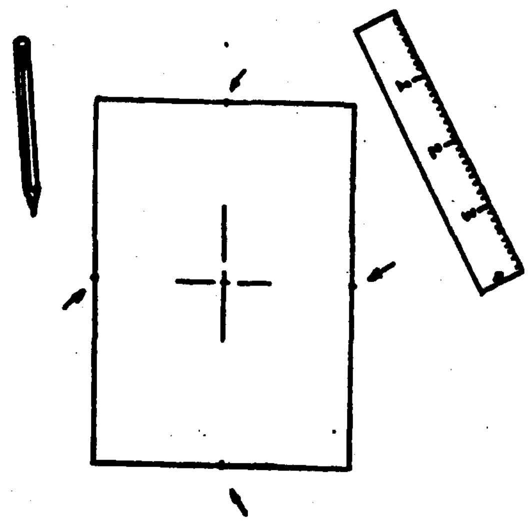

Appendix (continued)

PICTURE

Contextual

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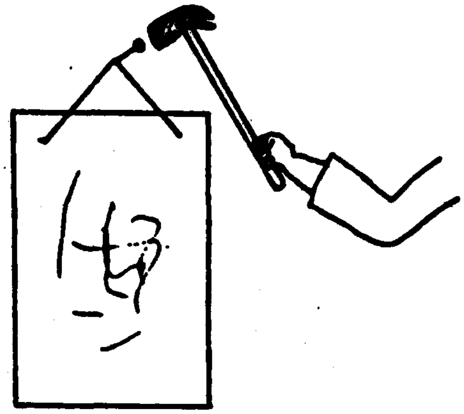

Depiction of Completed Assemblies

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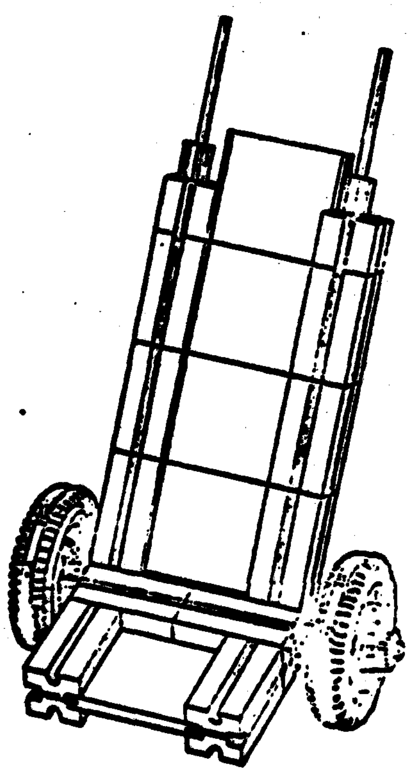

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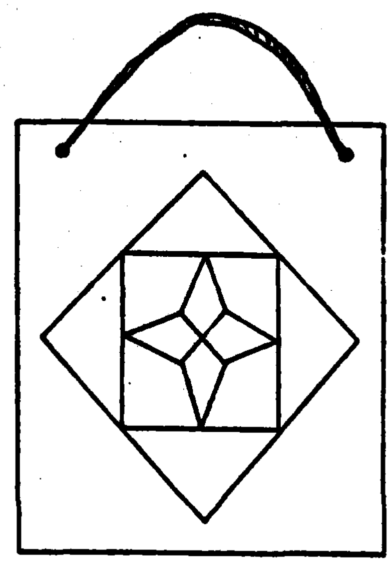

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